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Creighton, IV

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(54) **MAGNETIC NAVIGATION AND IMAGING SYSTEM**

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(51) **Int. Cl.**
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A61B 8/14 (2006.01)

(52) **U.S. Cl.** **73/602**; 600/437; 600/114; 600/9; 128/899

(58) **Field of Classification Search** 600/407; 73/602; 128/899
See application file for complete search history.

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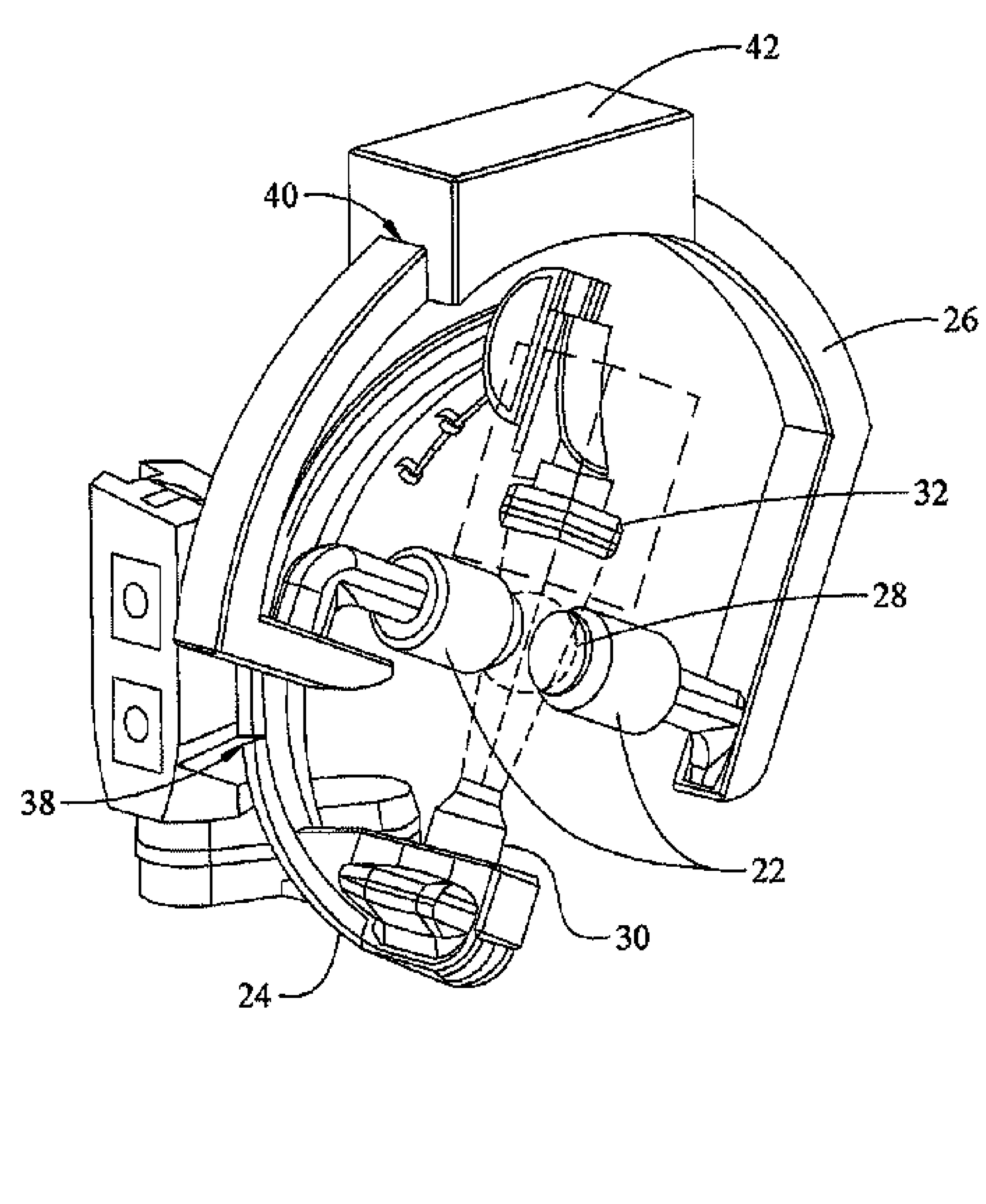
(57) **ABSTRACT**

A system for imaging and magnetically navigating a medical device within an operating region in a subject's body includes a first C-arm and a second C-arm. The system includes an imaging beam source and an imaging beam receiver mounted on the first C-arm disposed on opposite sides of the operating region to image the operating region. The system includes a pair of magnetic pods, which are movably mounted on either the first or second C-arm. The magnetic pods are movable between an imaging position and a navigating position in which the pods are disposed on opposite sides of the operating region in the same plane as at least one imaging beam source. The second C-arm is movable between an imaging position in which the imaging beam source and imaging beam receiver on the second C-arm is positioned so that the imaging beam sources and receivers are in the same plane.

20 Claims, 18 Drawing Sheets



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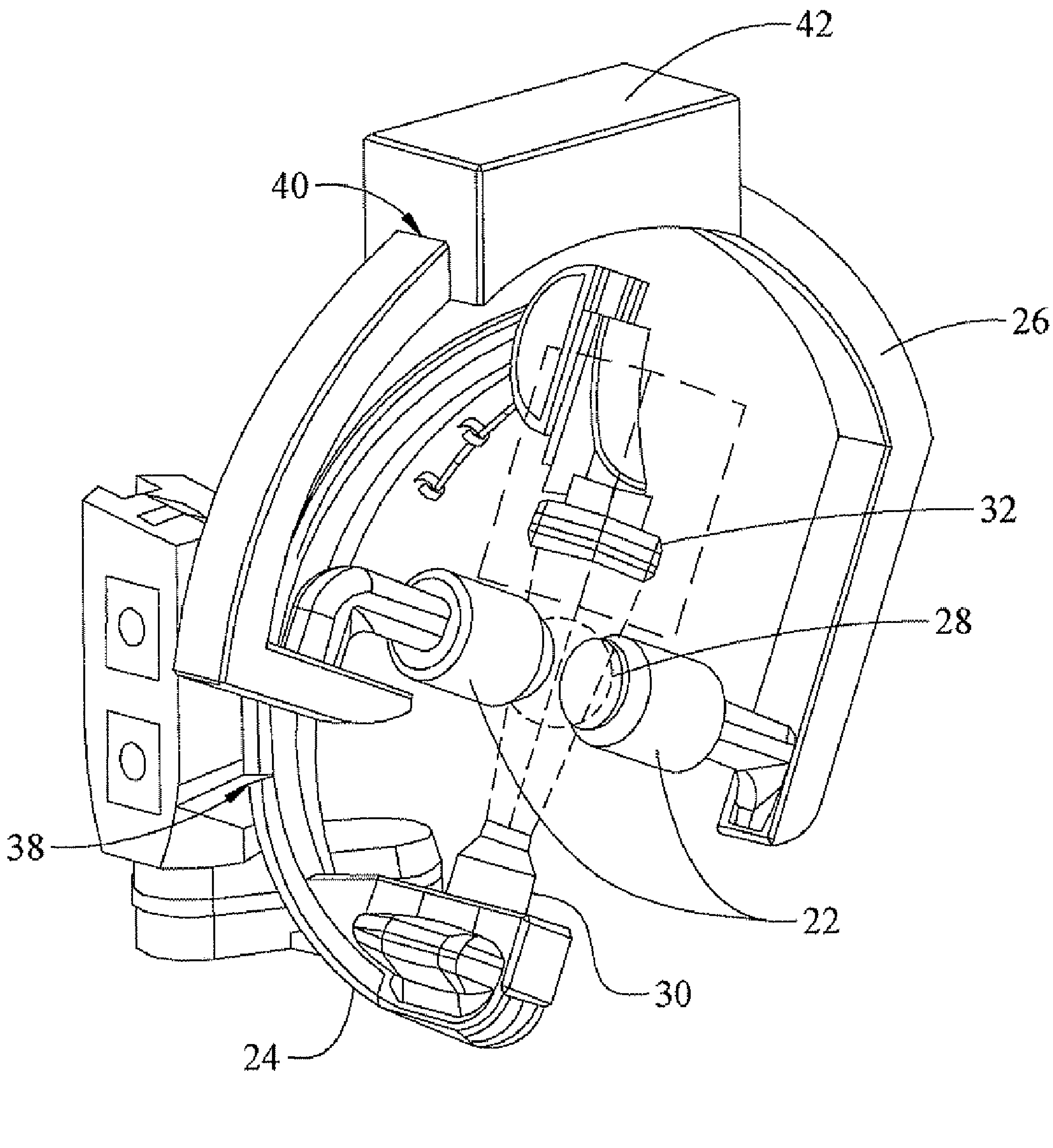

Fig. 1

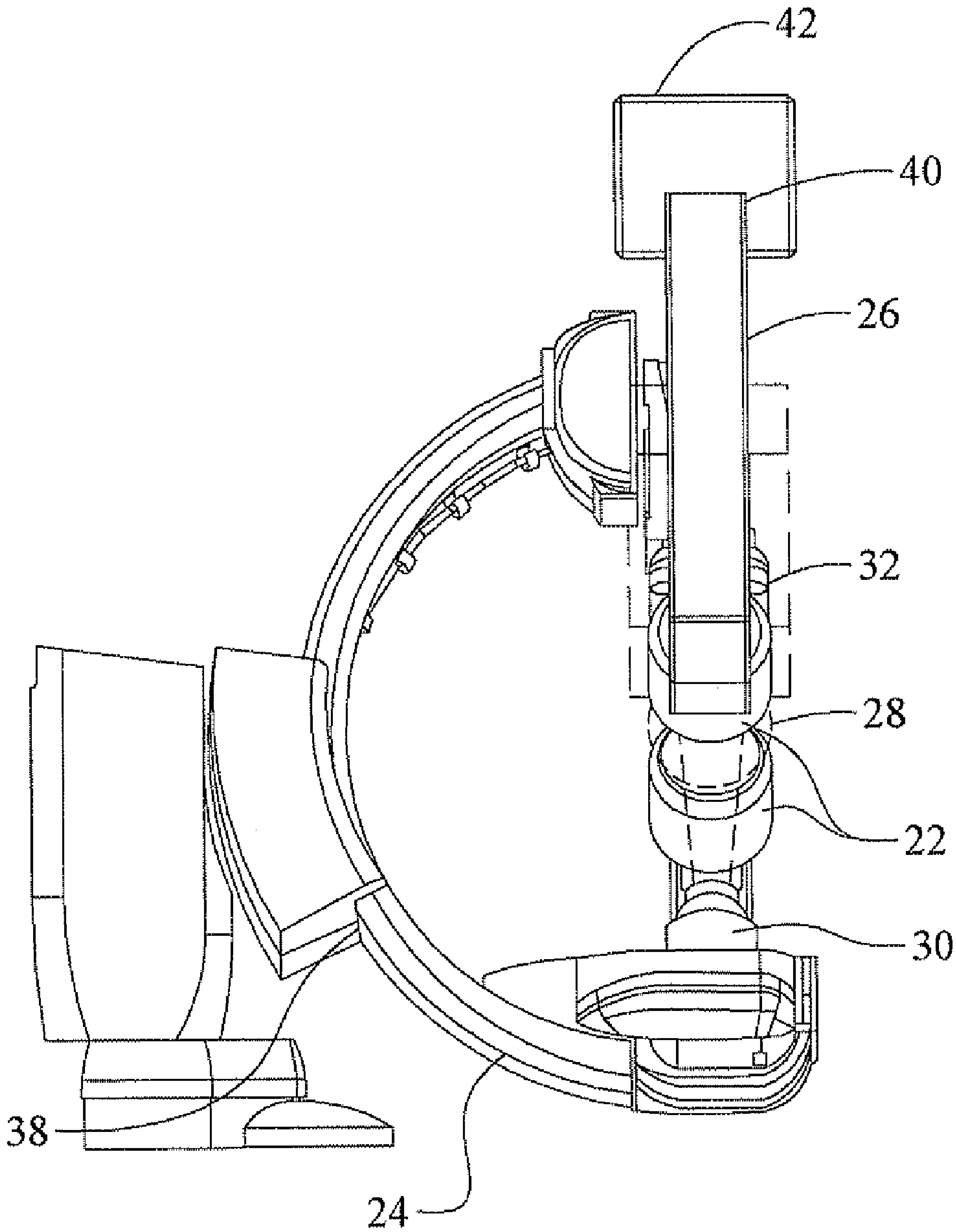

Fig. 2

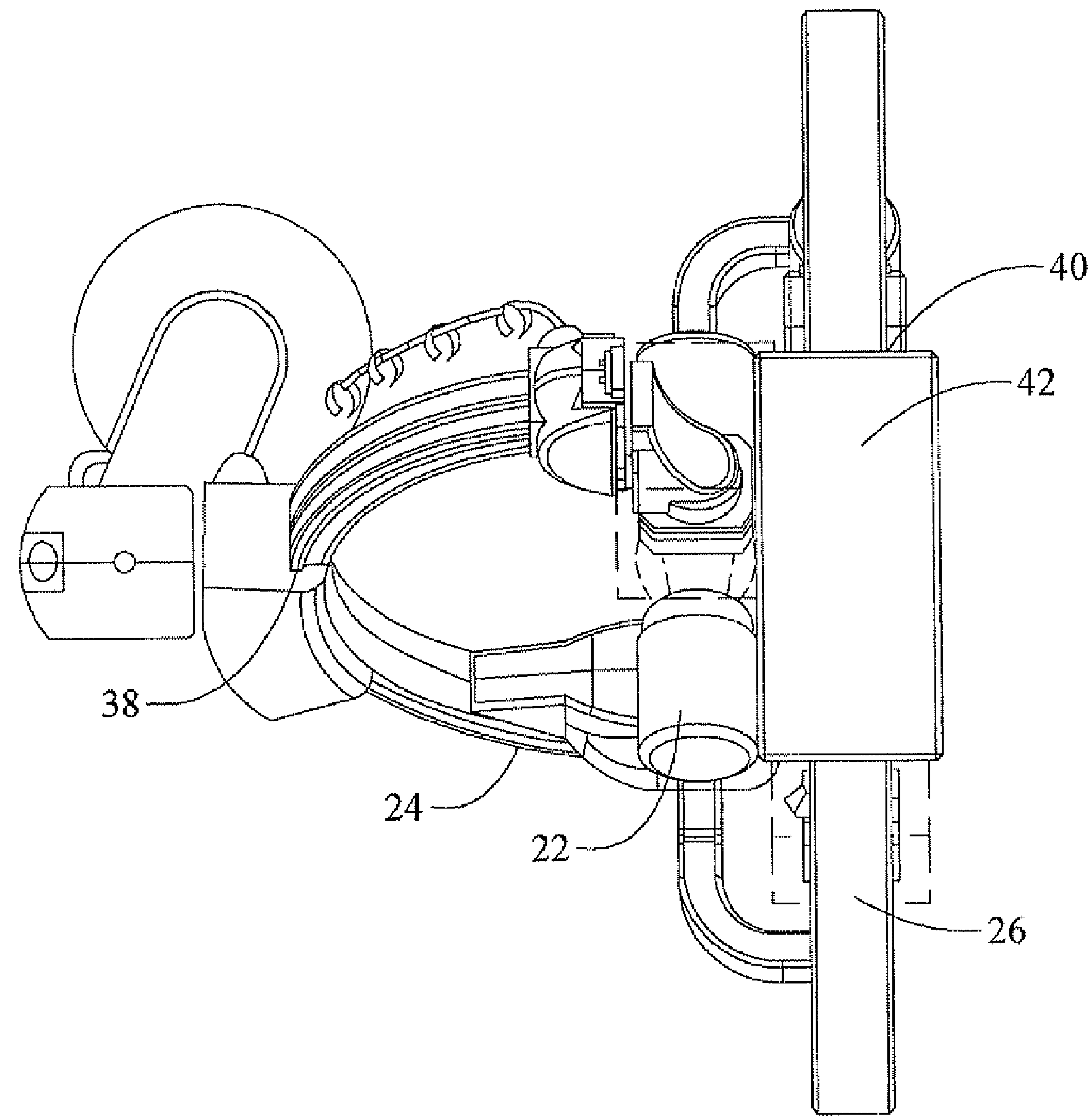

Fig. 3

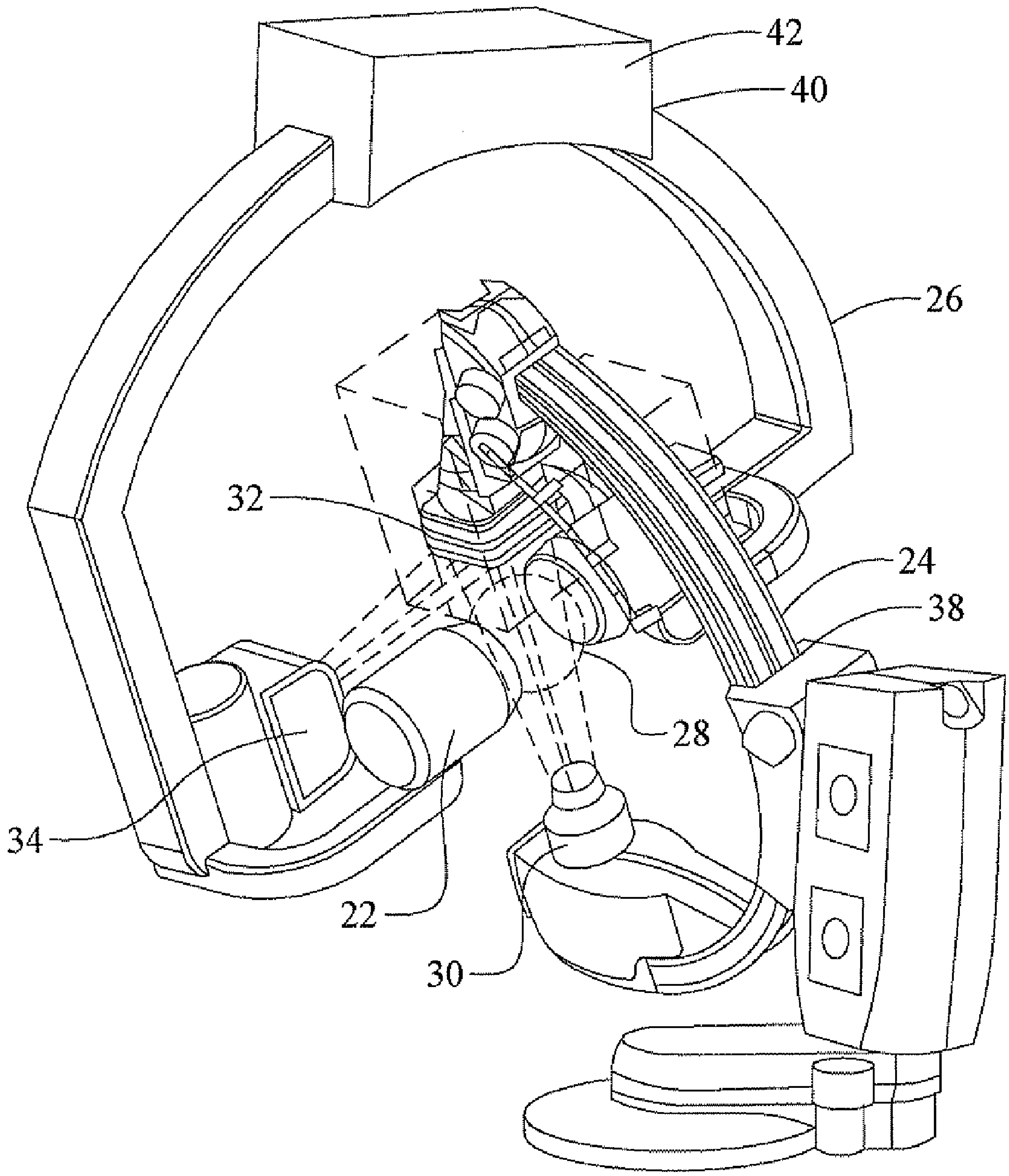

Fig. 4

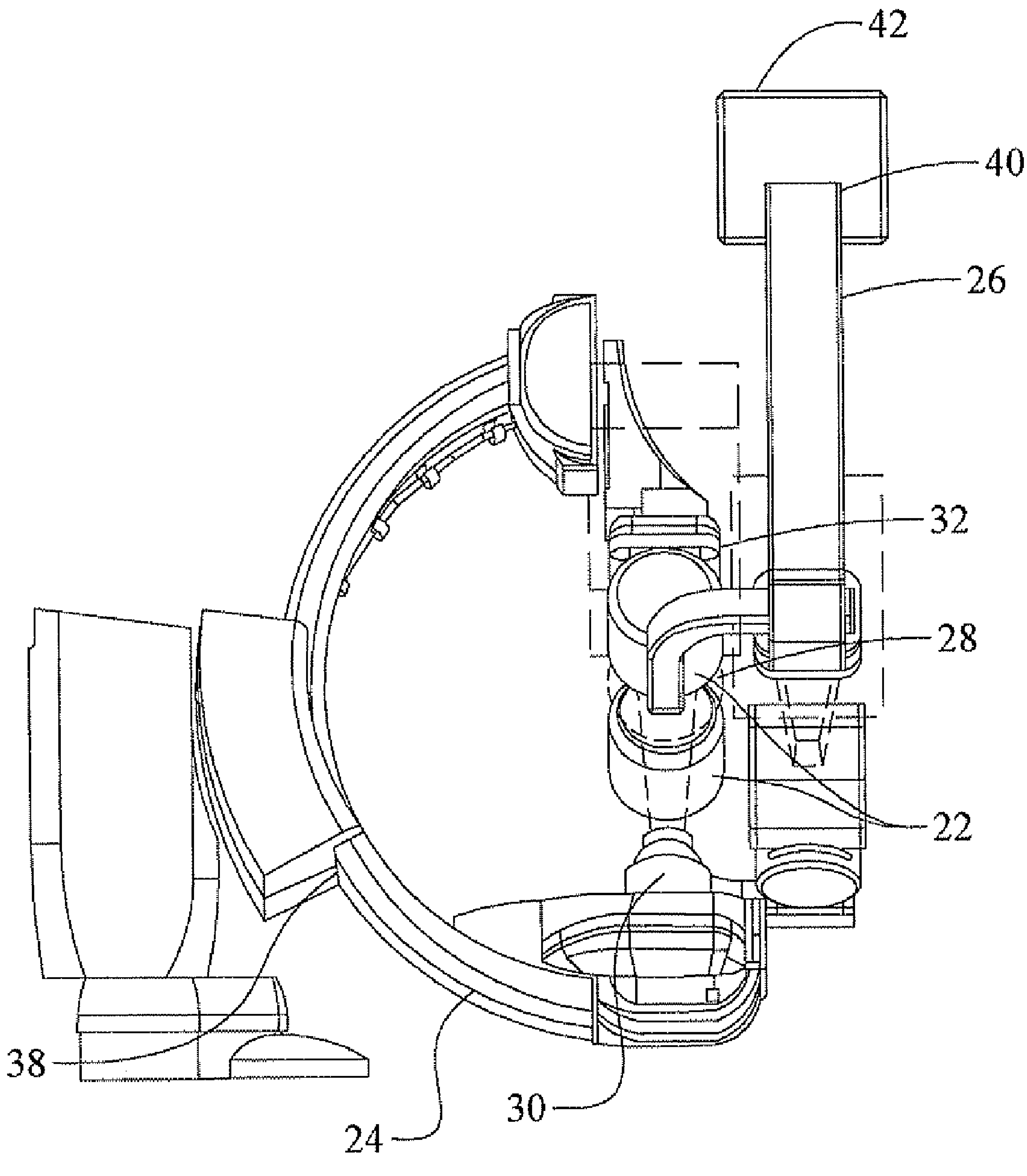

Fig. 5

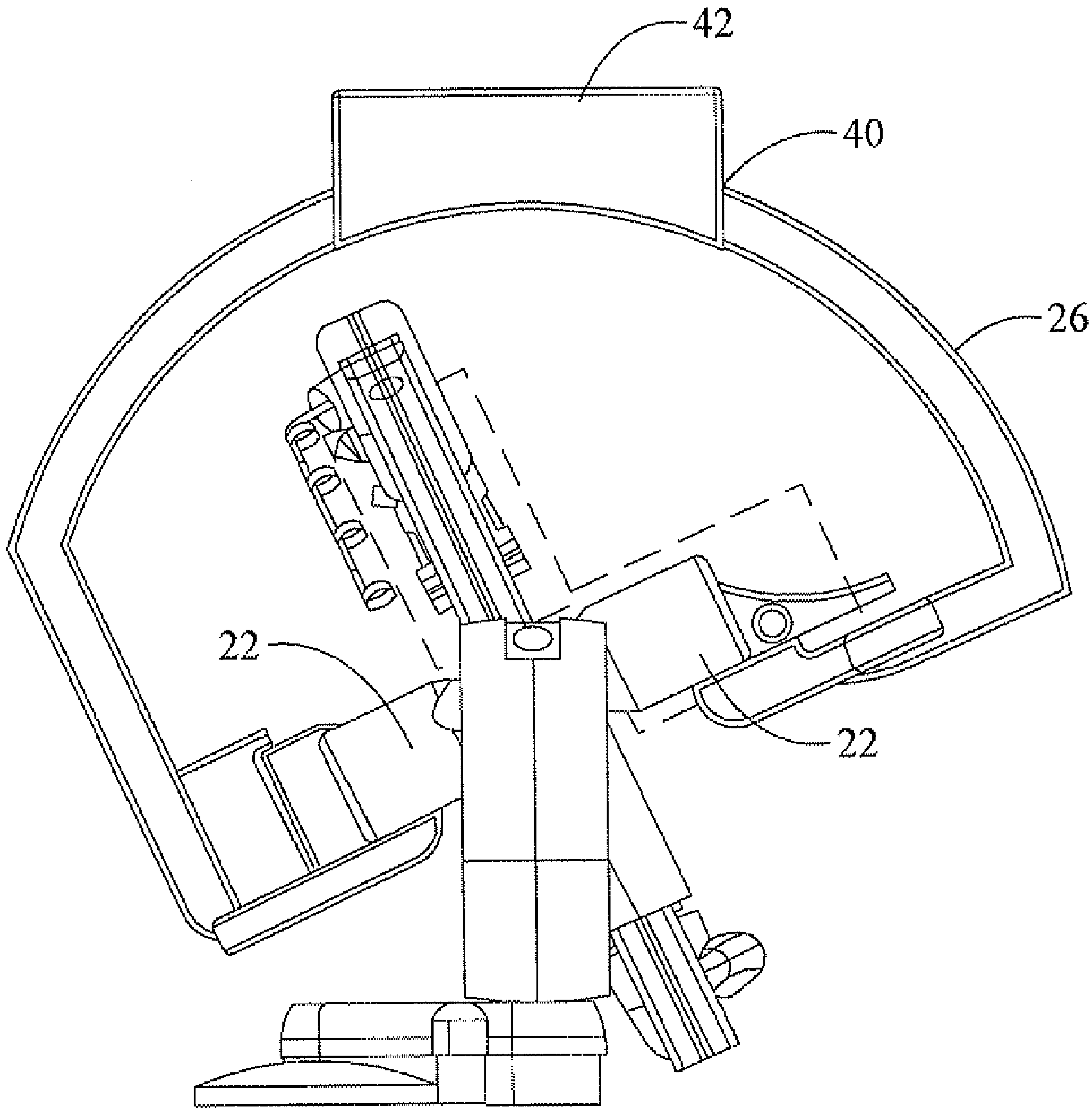

Fig. 6

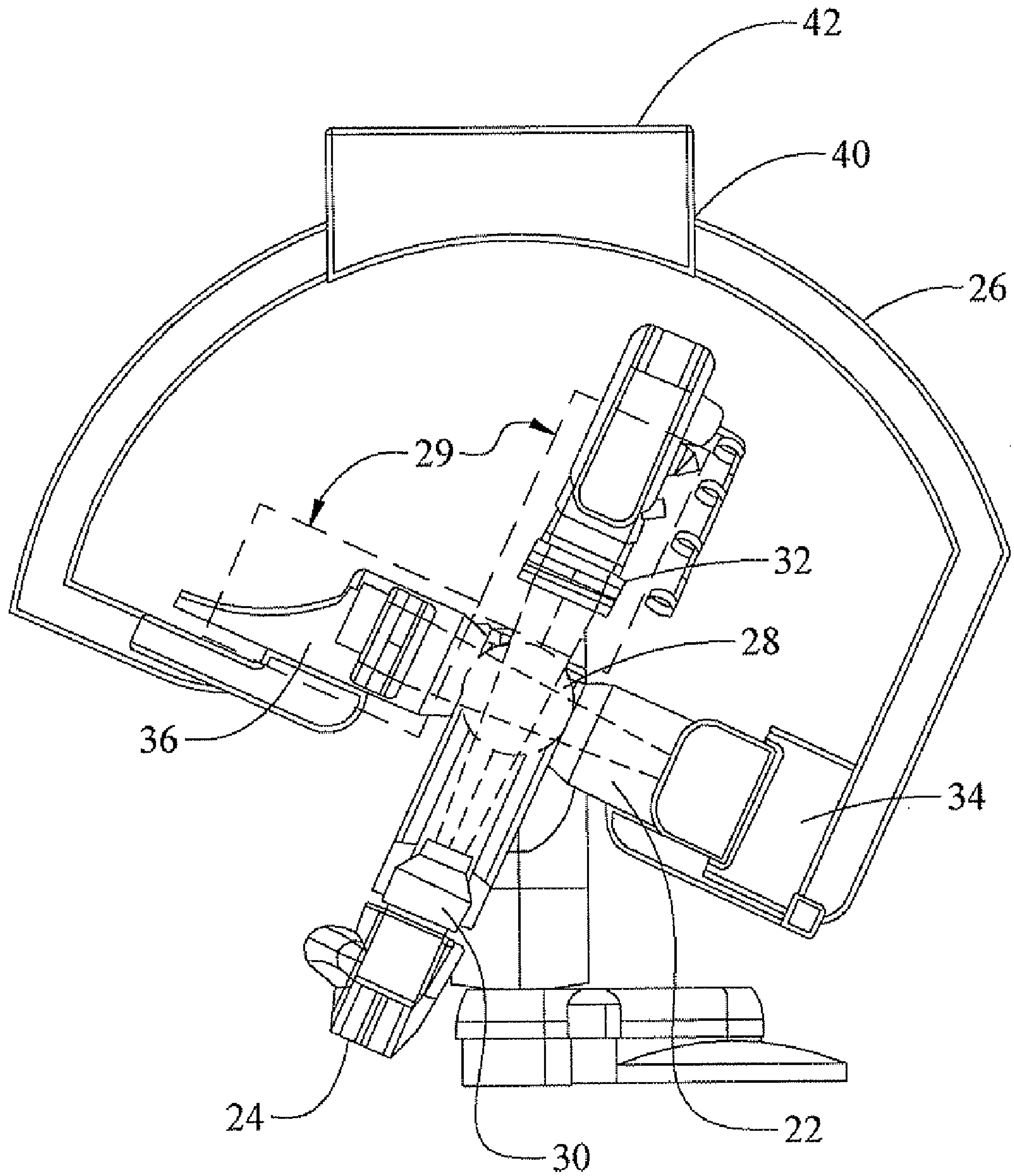

Fig. 7

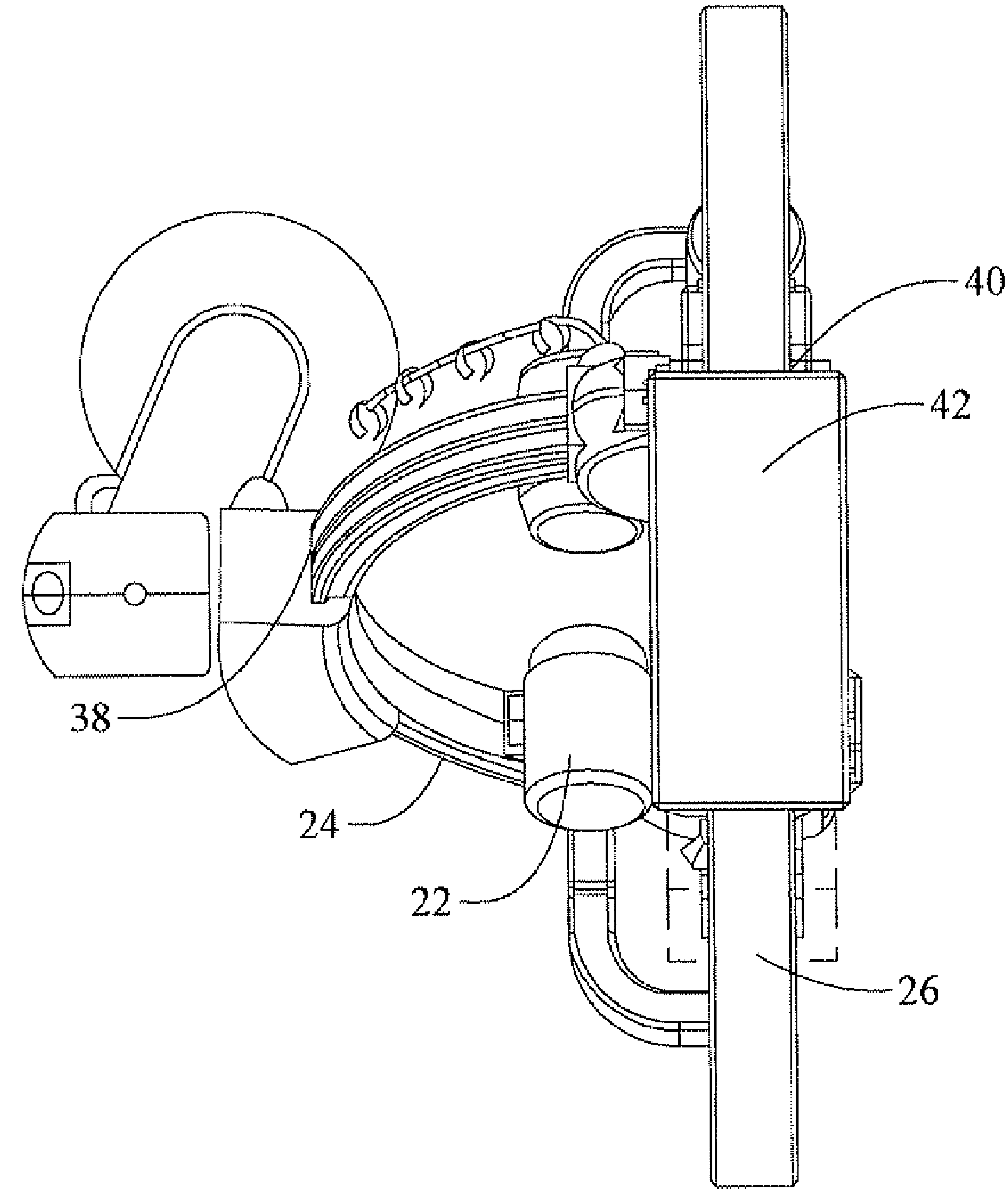

Fig. 8

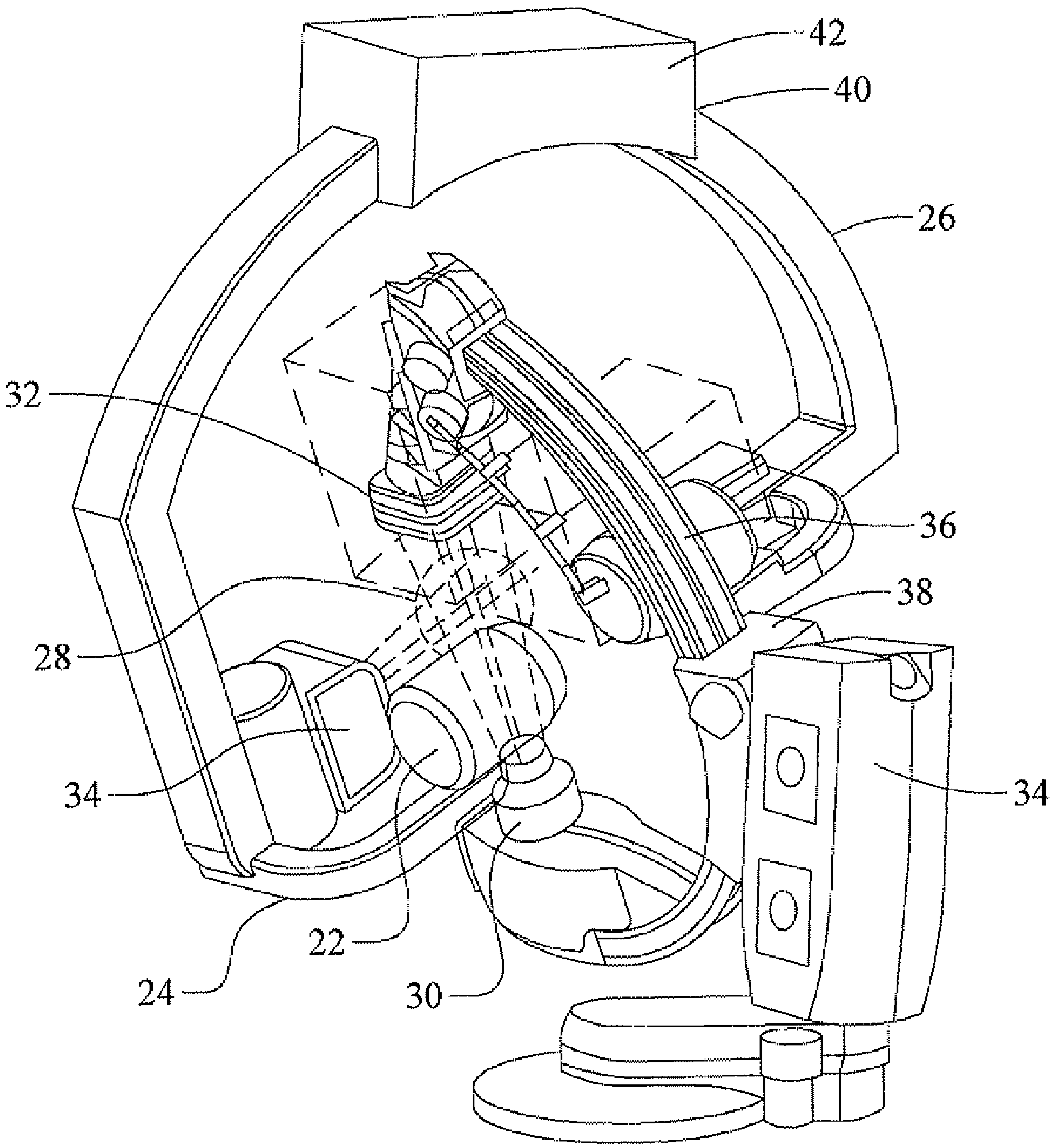

Fig. 9

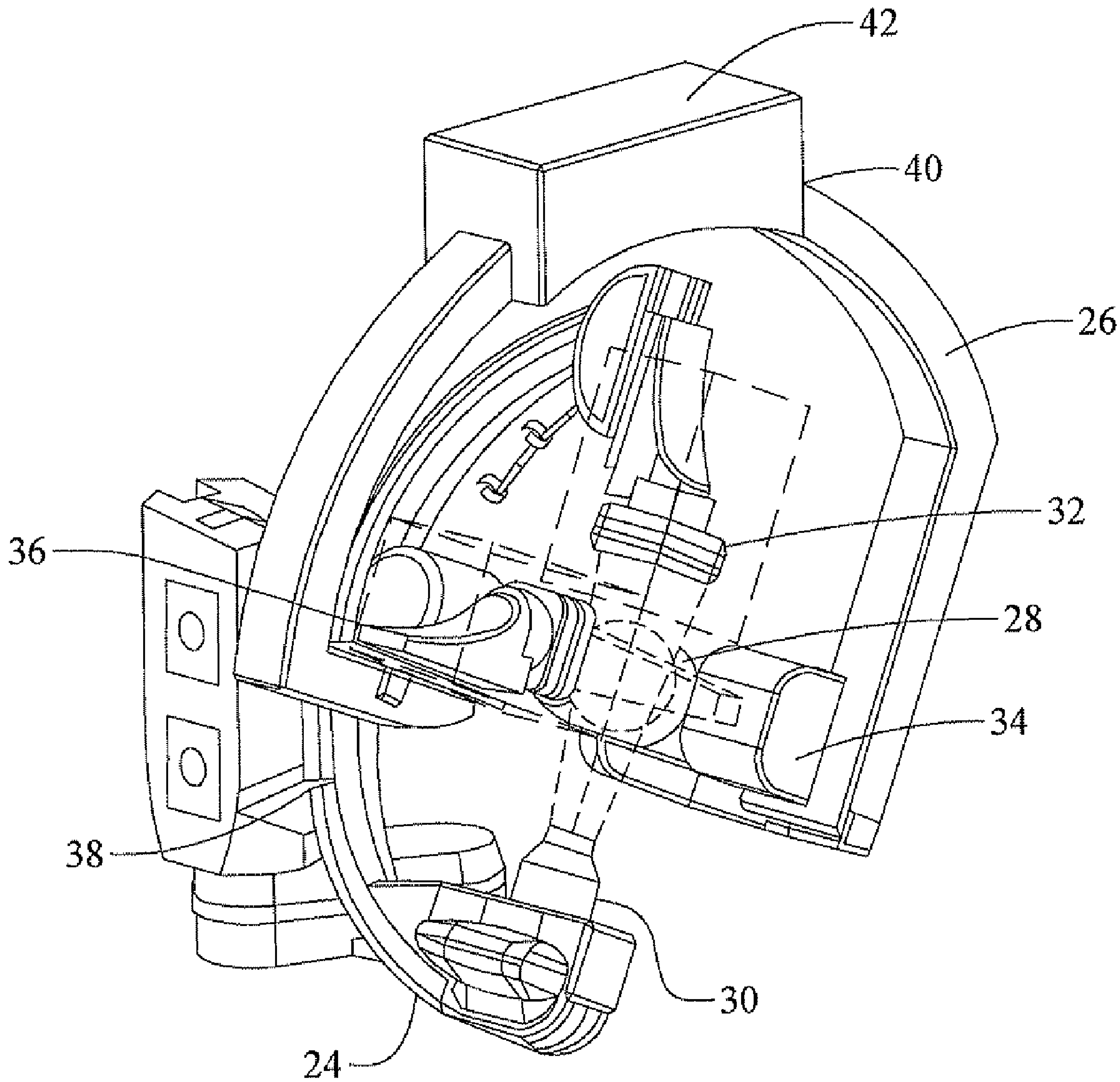

Fig. 10

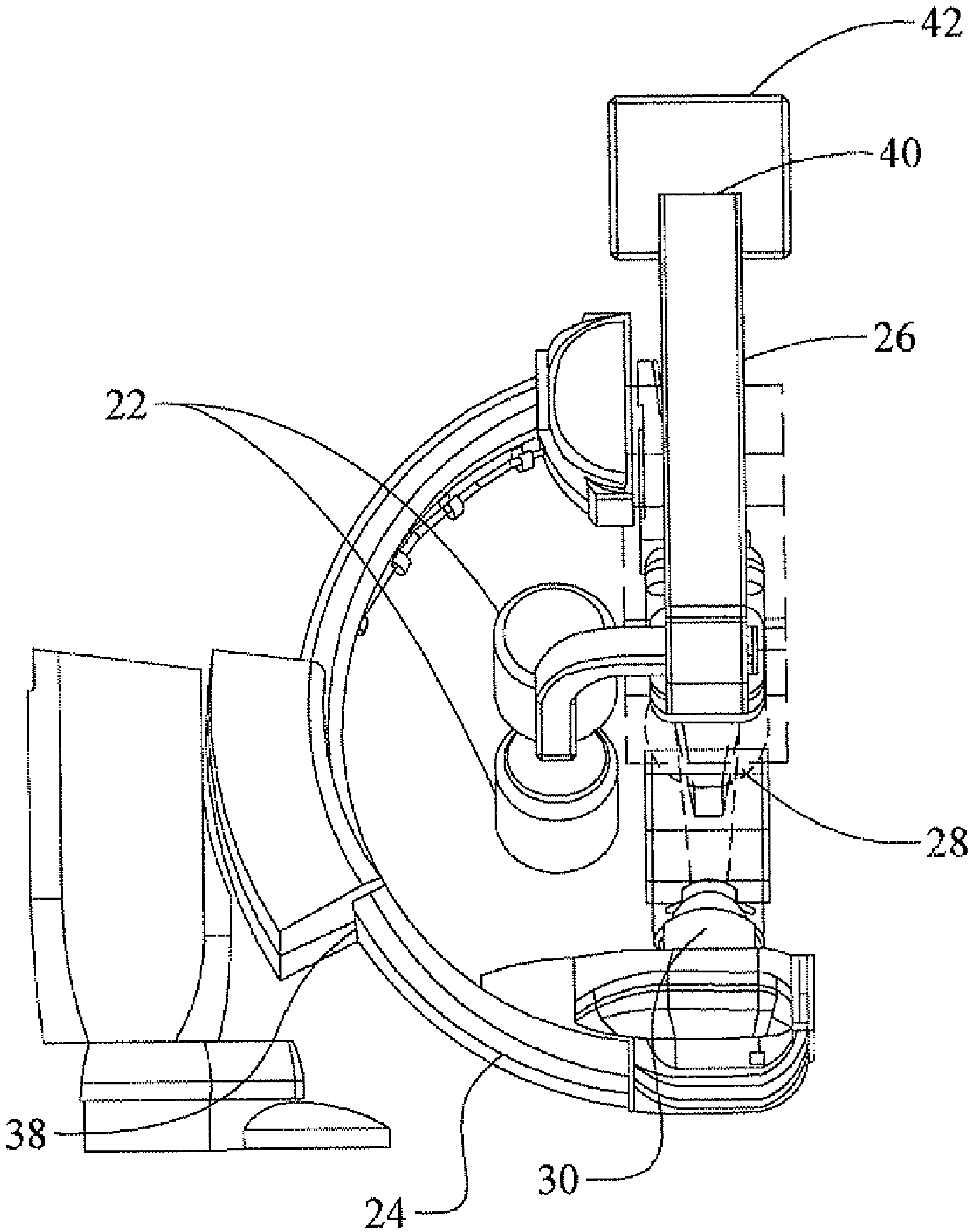

Fig. 11

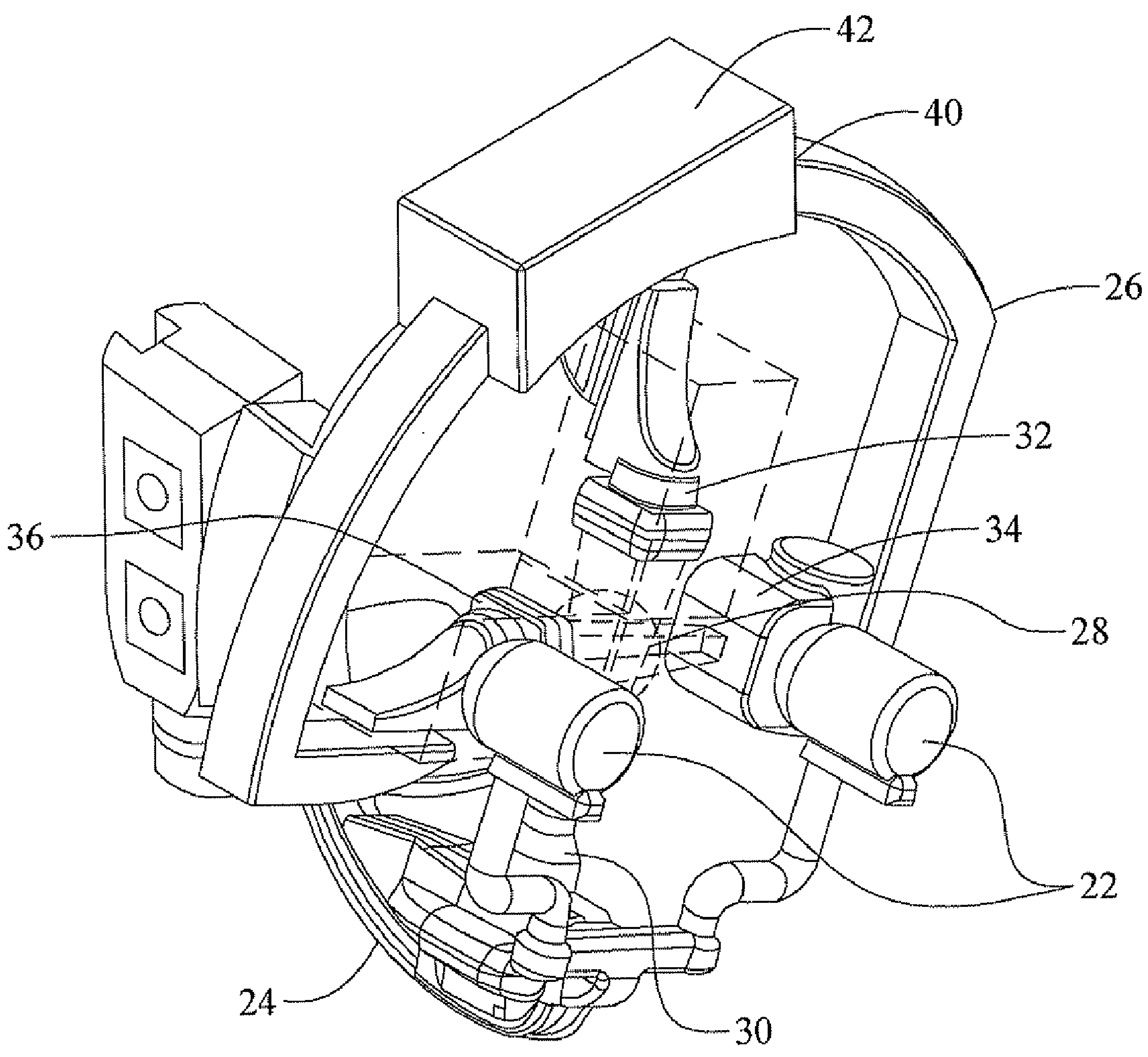

Fig. 12

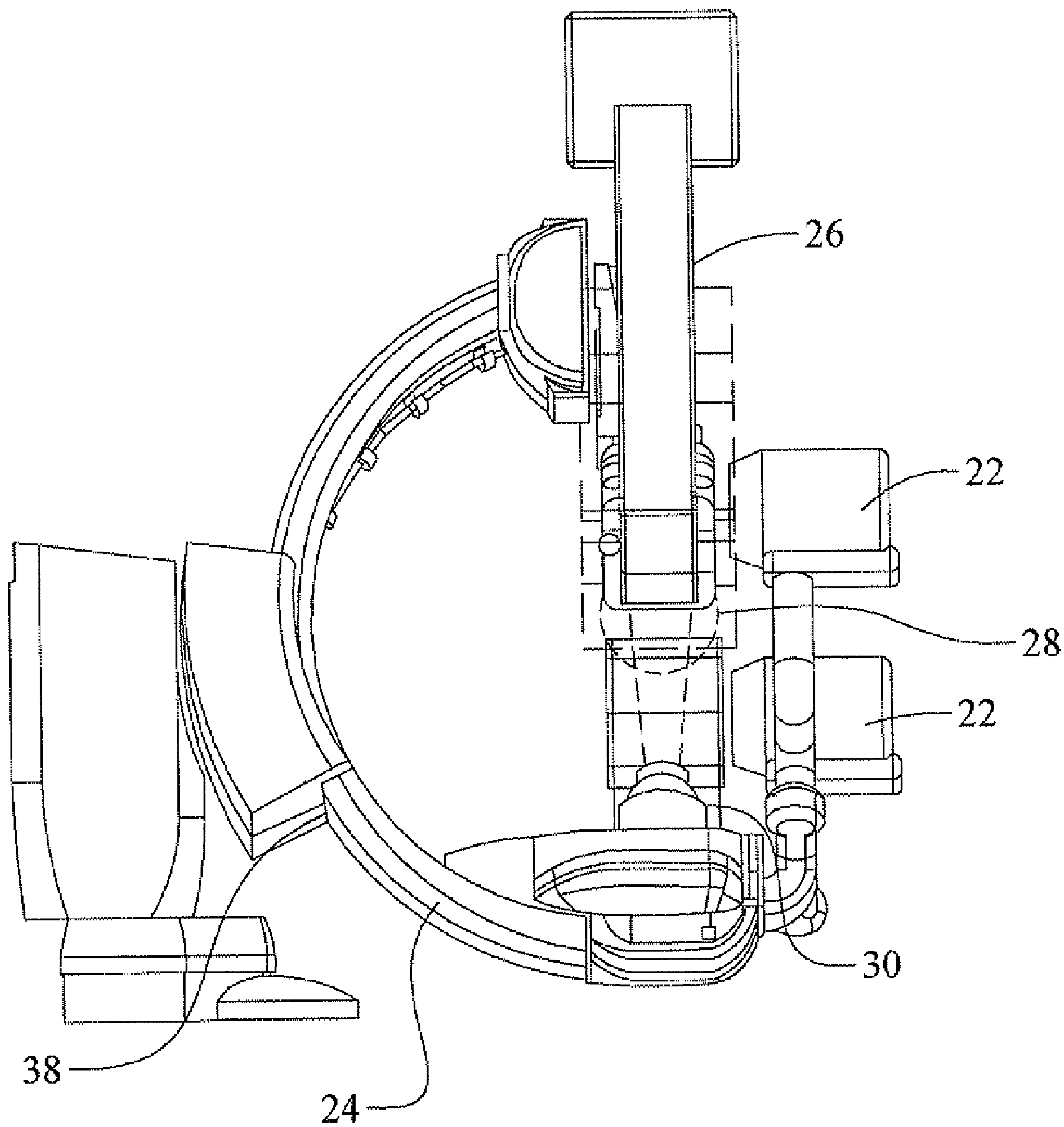

Fig. 13

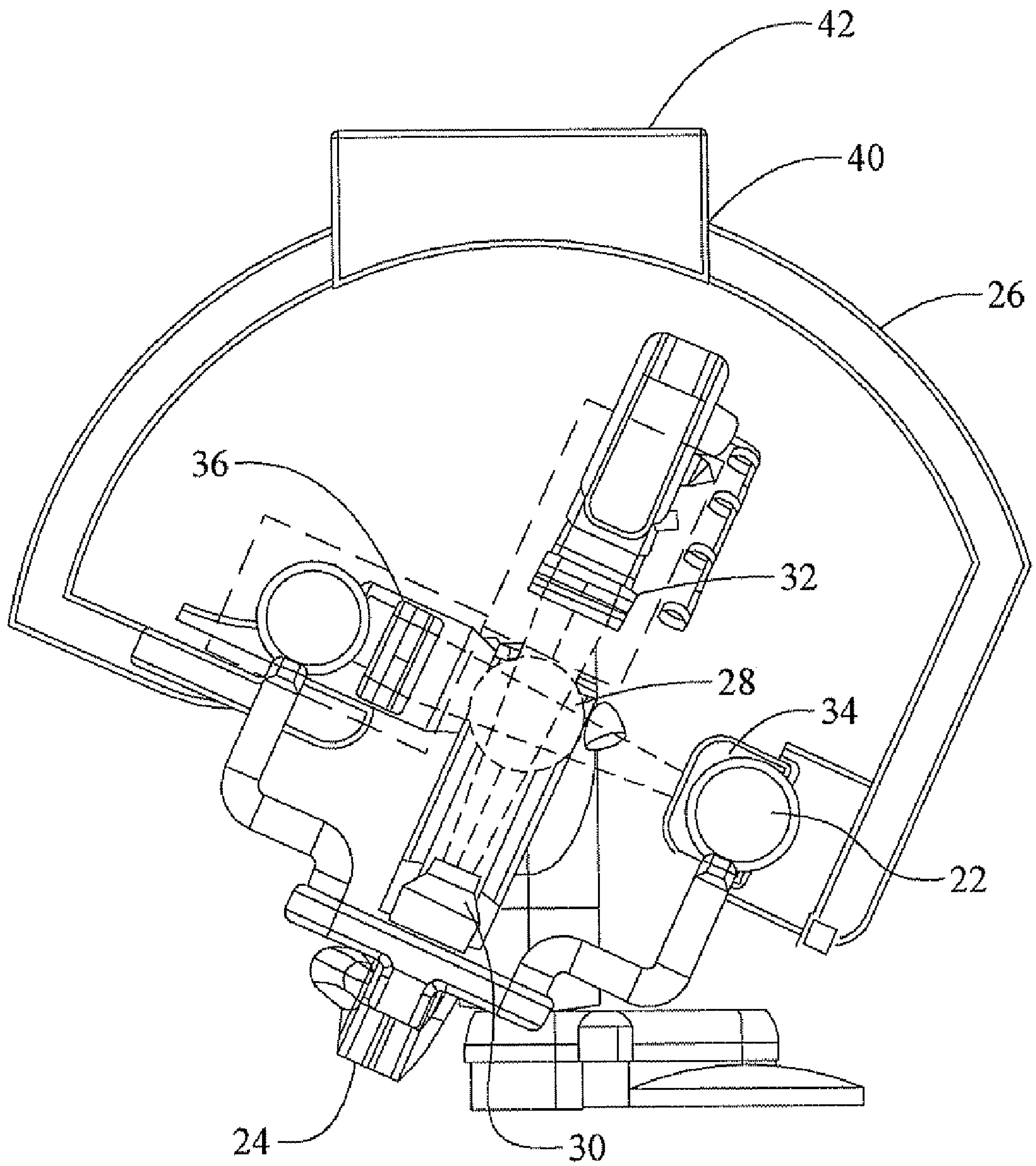

Fig. 14

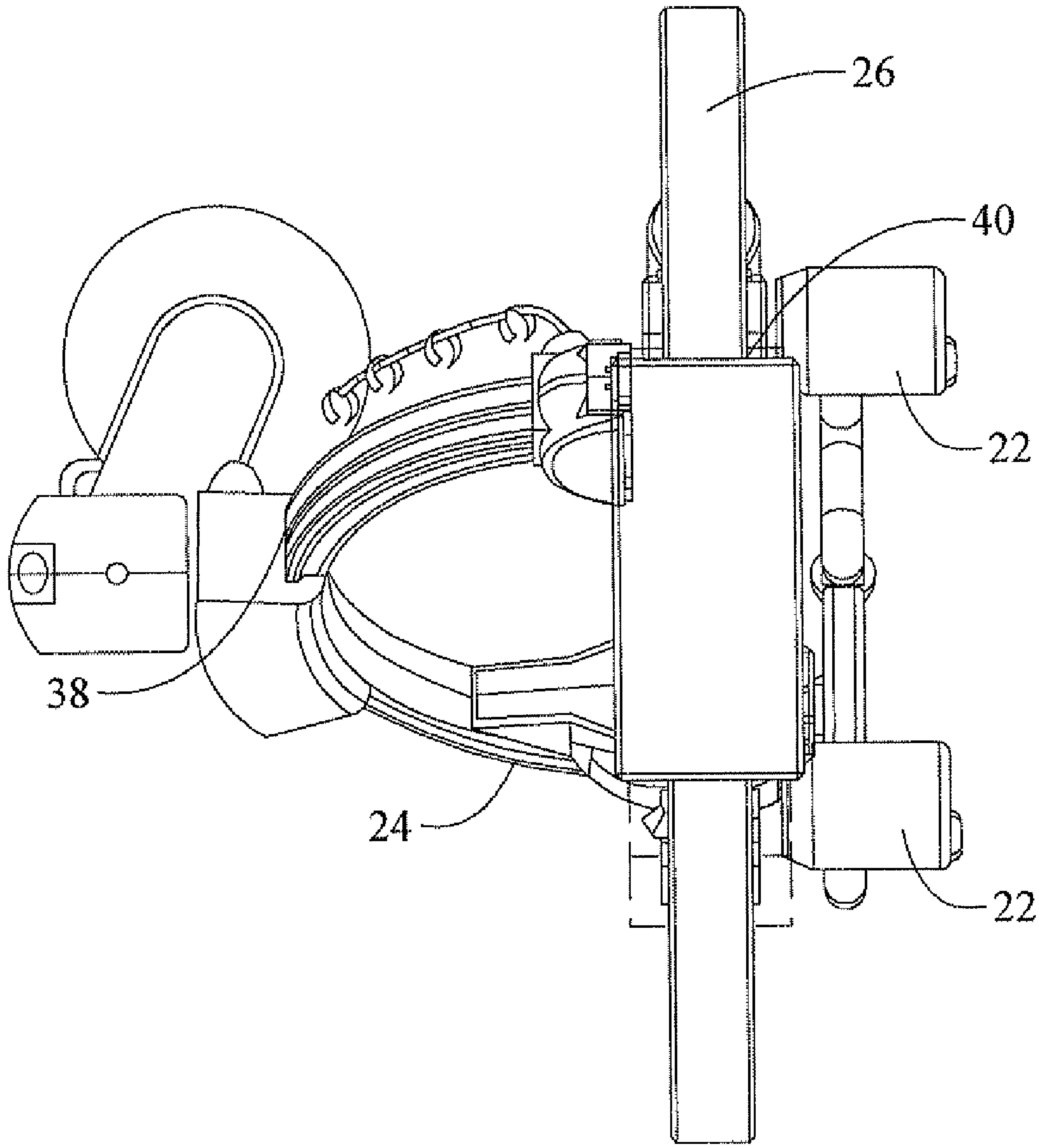

Fig. 15

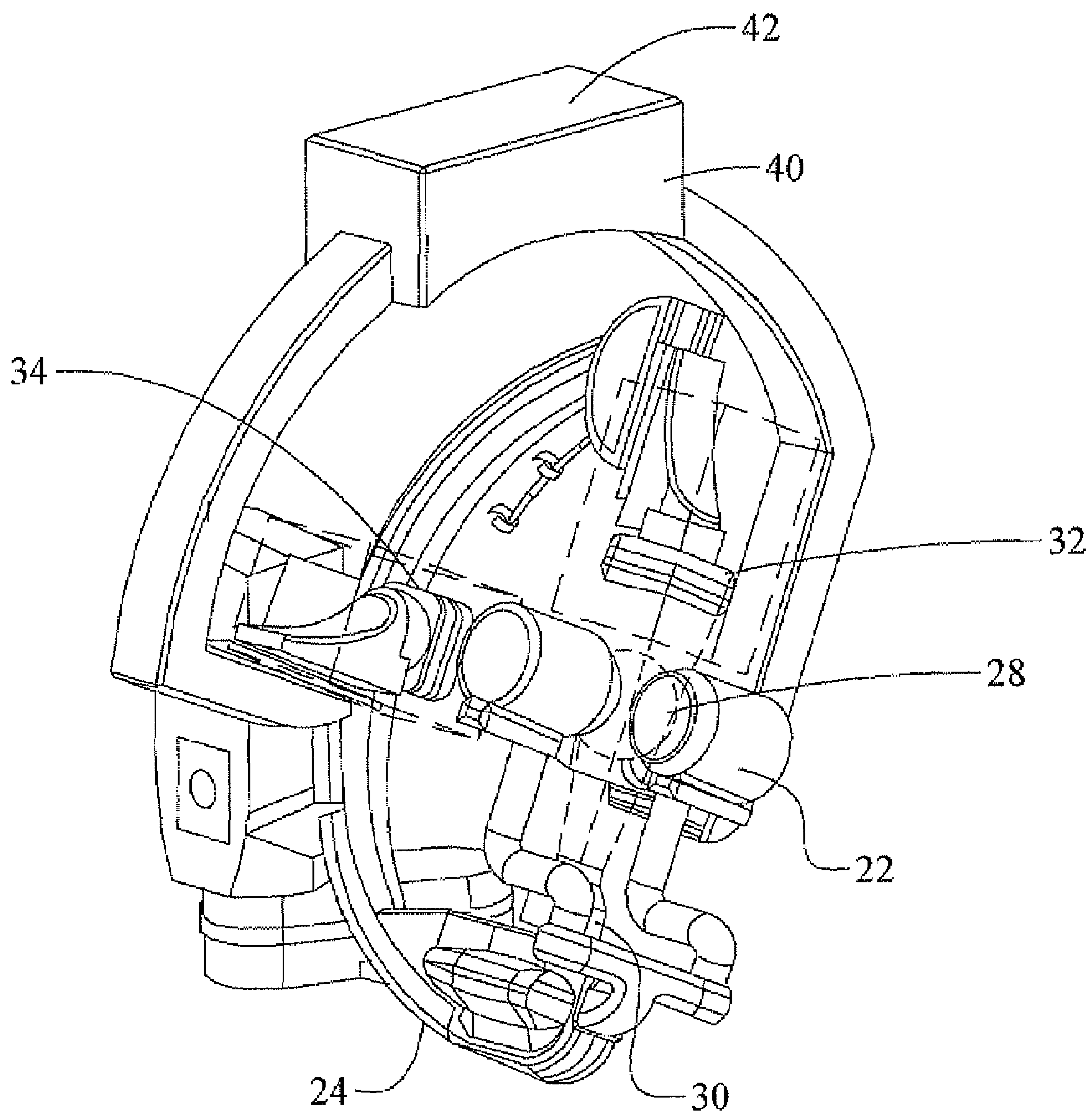

Fig. 16

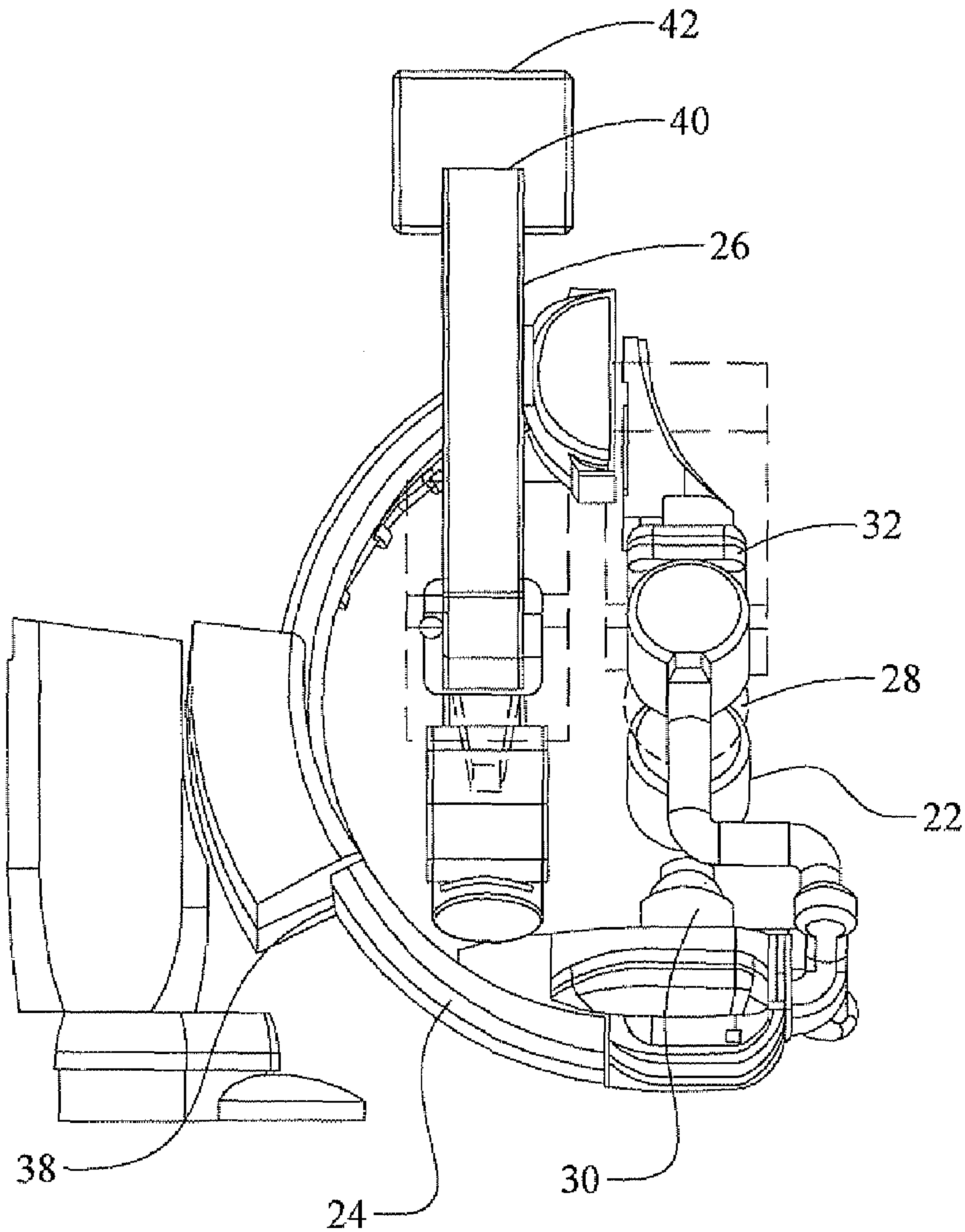

Fig. 17

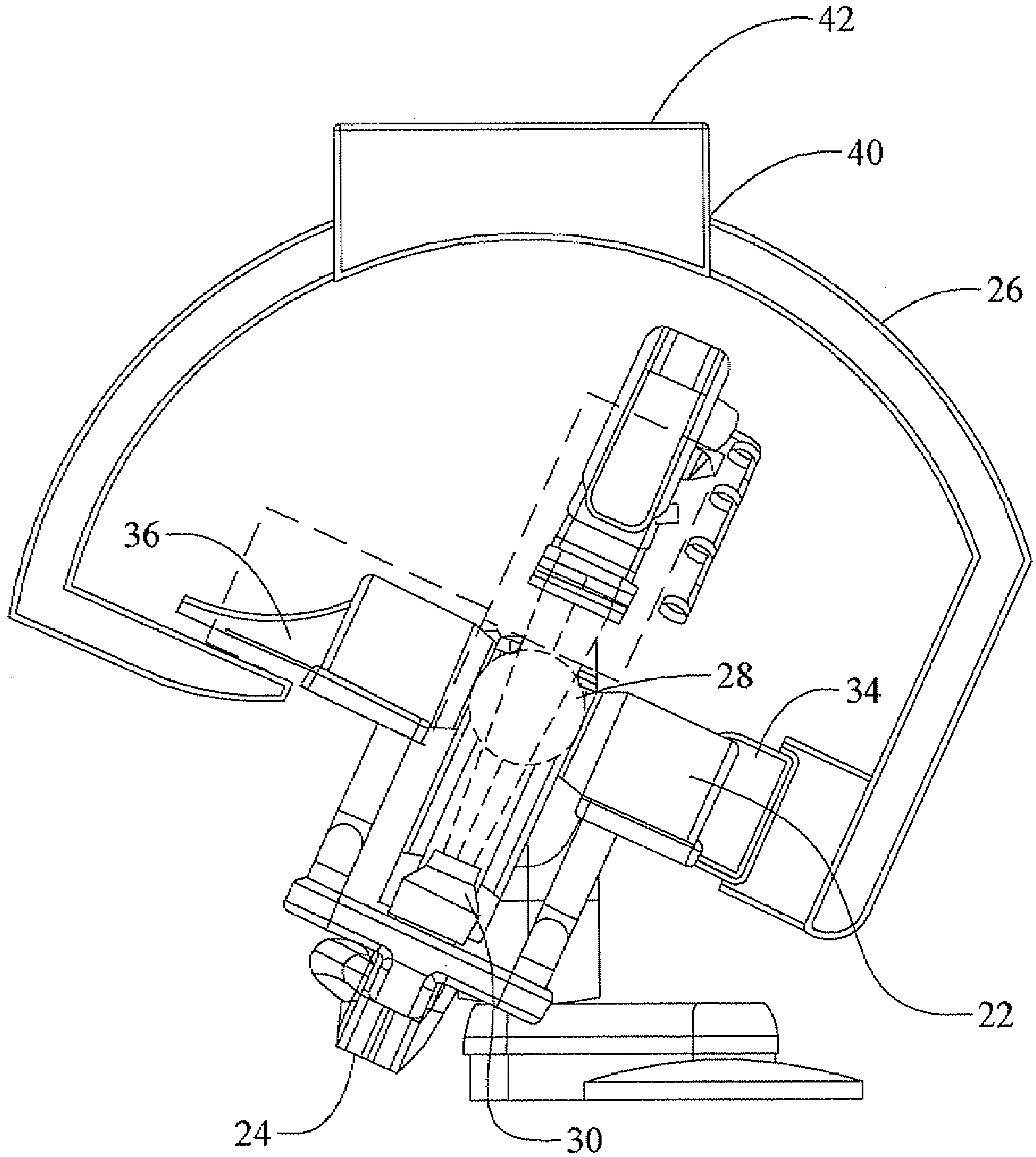

Fig. 18

MAGNETIC NAVIGATION AND IMAGING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 60/697,822 filed on Jul. 8, 2005, the entire disclosure of which are incorporated herein by reference.

FIELD OF THE INVENTION

This invention relates to a magnetic surgery system, and in particular to an open magnetic surgery system that provides greater access to the patient for imaging and other purposes.

BACKGROUND OF THE INVENTION

A wide variety of minimally invasive surgical procedures have been developed which employ catheters, endoscopes, or other similar devices that can be navigated remotely from their distal ends. The catheter, endoscope or other medical device is manipulated through the tissue or through an existing body lumen or cavity using a guide wire or other mechanical means. Examples of such procedures include the treatment of aneurysms, arterial ventricular malformations, atrial fibrillation, ureteral stones, and investigations of lumen such as sigmoidoscopies and colonoscopies, ERCP's; and biliary duct examinations. While these procedures are highly beneficial to the patient, they are difficult and time consuming for the physician. Some procedures can only be performed by the most skilled surgeons.

Because of the small size of the vessels to be navigated, extremely high resolution and flexibly moveable fluoroscopes are needed to provide adequate imaging. These fluoroscopes are large instruments. Even now, accessibility of adequate imaging in the presence of equipment needed to navigate the catheters, endoscopes, or other similar devices through the vessels.

Systems have been disclosed for magnetic guidance of catheters and guidewires to facilitate navigation of difficult vascular turns. Imaging means can be used in conjunction with magnetically guided surgery. An example of such a system is described in U.S. utility patent application Ser. No. 09/020,798, filed Feb. 9, 1998, entitled "Device and Method for Specifying Magnetic Field for Surgical Applications," now U.S. Pat. No. 6,014,580. While magnetically guided surgery with such systems is practical, the sheer bulk and size of their magnetic systems results in less accessibility of the operating region of the patient than a surgeon might prefer. Also, imaging equipment (such as X-ray equipment) for observing the operating region has been fixed to the magnetic system assembly, or otherwise been immobile or of limited mobility relative to the magnets and/or the patient. This relative immobility tends to reduce the ability of the surgeons to see the medical operating device within the patient, making the operation somewhat more difficult for the surgeon and somewhat riskier for the patient than might otherwise be the case. It would therefore be desirable to provide an apparatus for magnetically-assisted surgery that provides flexibility of both the imaging and of the magnetic field application.

A difficulty associated with magnetic guidance is that the magnetic field source needed to guide the medical devices within small vessels and body lumens may be relatively large. The distance between the magnet field source and the operating region is also a factor in providing a system for applying magnetic fields for navigation, while maintaining an "openness" and accessibility of imaging systems as described above.

SUMMARY OF THE INVENTION

Embodiments of the systems of the present invention advance the art of simultaneous imaging and remote surgical navigation by combining navigation and imaging system equipment in a manner that improves flexibility and accessibility of both systems. In one embodiment of the present invention, a system for imaging and magnetically navigating a medical device within an operating region in a subject's body is provided that comprises a first C-arm and a second C-arm. The system comprises an imaging beam source and an imaging beam receiver mounted on the first C-arm and positioned to be disposed on opposite sides of the operating region to image the operating region. The system further comprises an imaging beam source and an imaging beam receiver mounted on the second C-arm and positionable to be disposed on opposite sides of the operating region to image the operating region. In this embodiment, the second C-arm is movable between an imaging position in which the imaging beam source and imaging beam receiver on the second C-arm is positioned so that the imaging beam sources and receivers are in the same plane, and a stowed position in which the second C-arm is in a navigating position. The system comprises a pair of magnetic pods movably mounted on the first C-arm, the magnetic pods being movable between a navigating position in which the pods are disposed on opposite sides of the operating region in the same plane as the imaging beam source and the imaging beam receiver, for applying a navigating magnetic field of at least 0.08 T in any direction to the operating region, and a stowed position in which the magnets are moved out of the plane to accommodate the imaging beam source and imaging beam receiver on the second C-arm in its imaging position. The imaging beam source and the imaging beam receiver on the first C-arm are positioned so that a line between the imaging beam source and receive is generally perpendicular to, and coplanar with a line between the magnet pods in their navigating position.

In another aspect of the present invention, a second embodiment of a system provides for quickly moving between a position for navigation operation and a position for imaging. In the second embodiment, the system comprises a first C-arm, and a second C-arm having an imaging beam source and beam receiver mounted generally adjacent the magnet pods, such that the second C-arm may move from a navigation position utilizing the magnet pods to an imaging position utilizing the imaging beam source and beam receiver. The system comprises an imaging beam source and an imaging beam receiver mounted on the first C-arm so that the imaging beam source and imaging beam receiver can be disposed on opposite sides of the operating region in the subject. The system also comprises a second C-arm movable relative to the first C-arm between a stowed position and an imaging position, and having an imaging beam source and an imaging beam receiver mounted on the second C-arm. When the second C-arm is in its imaging position, the imaging beam source and imaging beam receiver are disposed on opposite sides of the operating region, in substantially the same plane as the imaging beam source and imaging beam receiver on the first C-arm. The second C-arm comprises a pair of magnetic pods mounted on the first C-arm, the C-arm being movable between a navigating position in which the pods are disposed on opposite sides of the operating region in the same plane as the imaging beam source and the imaging beam receiver, for applying a navigating magnetic field of at least 0.08 T in any direction to the operating region, and a stowed position in which the magnets are not on opposite sides of the operating region to accommodate the imaging beam source and imaging beam receiver on the second C-arm in its imaging position. When in the stowed position, the imaging beam source and the imaging beam receiver on the second C-arm are positioned so that a line between the imaging beam source and receiver is generally perpendicular to, and coplanar with a line between the magnet pods in their navigating position.

Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. **1** is an isometric view of a first embodiment of magnetic navigation and imaging system, showing the first C-arm having an imaging beam and imaging receiver, and a second C-arm having magnet pods perpendicular to the imaging beam;

FIG. **2** is a side elevation view of the system of the first embodiment;

FIG. **3** is a top end elevation view of a magnetic navigation and imaging system of a second embodiment;

FIG. **4** is an isometric view of the system of the second embodiment, showing the magnet pods on the second C-arm perpendicular to the imaging beam and imaging receiver on the second C-arm;

FIG. **5** is a side elevation view of the system of the second embodiment shown in FIG. **4**;

FIG. **6** is a rear end elevation view of the system of the second embodiment shown in FIG. **4**;

FIG. **7** is a front elevation view of the system of the second embodiment;

FIG. **8** is a top end elevation view of the system of the second embodiment;

FIG. **9** is a front perspective view of the system of the second embodiment, showing the first C-arm having an imaging beam and imaging receiver, and a second C-arm having magnet pods perpendicular to the imaging beam;

FIG. **10** is the system shown in FIG. **9** viewed from a rear perspective view;

FIG. **11** is a side elevation view of the system of the second embodiment in accordance with the present invention;

FIG. **12** is an isometric view of a third embodiment of a magnetic navigation and imaging system in accordance with the present invention;

FIG. **13** is a left side elevation view of the system of the third embodiment, showing the imaging beam and imaging receiver on the first C-arm in the same plane as the imaging beam and receiver on the second C-arm, with the magnet pods moved out of the plane;

FIG. **14** is a front elevation view of the system of the third embodiment, showing the imaging beam on the first C-arm and the imaging beam on the second C-arms perpendicular to each other and aligned with the patient;

FIG. **15** is a top elevation view of the system of the third embodiment;

FIG. **16** is an isometric view of the imaging beam and receiver of the first C-arm on both sides of the patient's body, and perpendicular to the navigational magnet pods;

FIG. **17** is a side elevation view of the system shown in FIG. **16**; and

FIG. **18** is a front elevation view of the system shown in FIG. **16** in accordance with the present invention.

Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The following description of the various embodiment(s) are merely exemplary in nature and are in no way intended to limit the invention, its application, or uses.

In one first embodiment of the present invention, a system that enables both imaging and magnetic navigation within an operating region of a subject's body is provided. The system comprises magnetic navigational equipment **22** that provides navigation control in an operating region **28** of a subject's body, as well as imaging equipment for procedures where anatomical views of the patient may be required during the procedure. The system generally comprises a first imaging equipment support structure having a generally C-shaped configuration **24**, and a second equipment support structure having a generally C-shaped configuration **26**. The first and second C-arm structures are preferably mounted on tracks that enable the C-arms to rotate circumferentially about an operating region **28** of the subject's body as shown in FIG. **1**.

In the first embodiment, the system comprises a first C-arm **24** with an imaging beam source **30** and an imaging beam receiver **32** that are mounted on the first C-arm **24** and positioned to be disposed on opposite sides of the operating region **28** for imaging the operating region. The imaging beam receiver **32** may be configured to accommodate an imaging plate of approximately 20 centimeters, and may preferably accommodate an imaging plate of up to approximately 30 centimeters. The operating region **28** is represented by a sphere of approximately 12 inch diameter as shown in FIG. **1**, which represents a patient's head plus 1 inch of additional clearance. The system also comprises a second C-arm **26** having magnetic navigational equipment **22** mounted thereon, which magnetic navigational equipment is positionable to be disposed on opposite sides of the operating region **28** to image the operating region. The first C-arm **24** and second C-arm **26** are movably mounted via tracks **38** and **40**, to permit coordinated simultaneous rotation of the first C-arm **24** and the second C-arm **26** in a generally circumferential arc about the operating region **28** of the subject's body as shown in FIG. **1**. The first and second C-arms may be controllably rotated about the patient by a servo drive motor mechanisms preferably controlled by a computer system that is integrated with both the imaging and navigational equipment. In this manner, the computer control of the imaging and navigational equipment may provide for seamless coordination of movement of both systems to provide either imaging operation, navigation control or both. The first C-arm **24** comprises an imaging beam source **34** and imaging beam receiver **36** that are positioned so that they are in the same plane as the magnetic navigational pods **22** on the second C-arm **26**. The magnetic pods **22** are disposed on the second C-arm **26** on opposite sides of the operating region **28**, such that a line between the magnetic pods **22** is generally perpendicular to, and coplanar with a line between the imaging beam source **30** and the imaging beam receiver **32** mounted on the first C-arm **24**. The magnetic pods **22** are capable of applying a navigating magnetic field of at least 0.08 T in any direction to the operating region **28**. The pair of magnetic pods **22** are preferably positioned relative to each other to provide a 12 inch pod-to-pod separation. Such separation permits the magnetic navigation equipment to be utilized for INR or Neurosurgery therapies. The magnetic pods **22** each have a weight of approximately 120 pounds. The second C-arm **26** provides a minimum articulation of the magnetic pods **22** to ensure compatibility with secondary imaging equipment.

The first C-arm **24** is preferably mounted on a track **38** for enabling the C-arm to rotate about the radial center of the first C-arm **24**, such that the first C-arm **24** rotates in a generally circumferential arc about the operating region **28**. The track **38** is preferably mounted to a base unit having a drive mechanism for controlling the rotation of the first C-arm **24** about the operating region. In the first embodiment, a standing C-arm imaging system is provided as shown in FIG. **1**. The C-arm shown is preferably a standing Siemens C-arm imaging system, but may alternatively be any equivalent imaging system capable of rotation about an operating region of a patient. The base unit for the first C-arm may be positioned on the floor in a location relative to a horizontal support table **44** for the patient, such that a portion of the patient's body on the patient support table **44** is within the operating region **28**. The horizontal patient support table **44** is preferably movable in a direction along the longitudinal axis of the patient, to allow for positioning a desired area of the subject's body within the operating region **28**.

The first embodiment further comprises a second C-arm **26** that is mounted on a track support **40** for enabling the second C-arm to rotate about the radial center of the second C-arm **24**. The second C-arm **24** rotates in a generally circumferential arc about the operating region **28**. The track support **40** is preferably mounted via a motorized trolley or travel mechanism to an overhead linear track that is parallel to the longitudinal axis of the patient and/or support table. The overhead linear track comprises a pair of magnetic navigational pods that are disposed or mounted at the ends of the second C-arm such that a line between the imaging beam source **30** and receiver **32** on the first C-arm **24** is generally perpendicular to, and coplanar with a line between the magnetic navigational pods **22** mounted on the second C-arm **26**. The second C-arm **26** shown in FIG. **1** is an overhead secondary Siemens C-arm, but may alternatively be any equivalent system capable of rotation about an operating region of a patient.

Referring to FIGS. **3-11**, a second embodiment of a system is provided that enables both primary and secondary imaging as well as magnetic navigational control within a subject's body. The system comprises magnetic navigational equipment **22** that may be moved from a first navigational position to a second position for enabling secondary imaging equipment to have access to the operating region of the subject's body, for example, during a procedure where additional views of the patient are required for the procedure. The system generally comprises a first imaging equipment support structure **24** having a generally C-shaped configuration, and a second imaging equipment support structure **26** having a generally C-shaped configuration. The first and second C-arm structures **24** and **26** are preferably mounted on tracks **38** and **40** that enable the first and second C-arms **24** and **26** to rotate in a generally circumferential arc about an operating region **28** of the subject's body as shown in FIG. **3**.

In the second embodiment, the system comprises a first C-arm **24** with an imaging beam source **30** and an imaging beam receiver **32** that are mounted on the first C-arm **24** and positioned to be disposed on opposite sides of the operating region **28** for imaging the operating region. The imaging beam receiver **32** may be configured to accommodate an imaging plate of approximately 20 centimeters, and may preferably accommodate an imaging plate of up to approximately 30 centimeters, as shown by the region **29** in FIG. **7**. The operating region **28** is represented by a sphere of approximately 12 inch diameter as shown in FIG. **1**, which represents a patient's head plus 1 inch of additional clearance. The system also comprises a second C-arm **26** with an imaging beam source **34** and an imaging beam receiver **36** that are mounted on the second C-arm **26**. The imaging beam source **34** and receiver **26** are positionable to be disposed on opposite sides of the operating region **28** to image the operating region. The first C-arm **24** and second C-arm **26** are movably mounted via tracks **38** and **40**, to permit coordinated simultaneous rotation of the first C-arm **24** and the second C-arm **26** in a generally circumferential arc about the operating region **28** of the subject's body as shown in FIG. **1**. The first and second C-arms may be controllably rotated about the patient by a servo drive motor mechanisms preferably controlled by a computer system that is integrated with both the imaging and navigational equipment. In this manner, the computer control of the imaging and navigational equipment may provide for seamless coordination of movement of both systems to provide either imaging operation, navigation control or both.

The second C-arm **26** is movable between an imaging position and a navigating position. In the navigating position, a pair of magnetic pods **22** are disposed on opposite sides of and projecting towards the operating region **28**, in the same plane as the imaging beam source **30** and the imaging beam receiver **32** mounted on the first C-arm. The pair of magnetic pods **22** are mounted on the second C-arm **24** in a manner such that they extend from the second C-arm towards the patient. The magnetic pods **22** are capable of applying a navigating magnetic field of at least 0.8 T in any direction to the operating region **28**. The pair of magnetic navigation equipment pods **22** are preferably positioned relative to each other to provide a 12 inch pod-to-pod separation, which spacing provides for INR or Neurosurgery therapies. The magnetic pods **22** each have a weight of approximately 120 pounds. In the imaging position, the imaging beam source **34** and imaging beam receiver **36** on the second C-arm **26** are positioned so that the imaging beam sources **30**, **34** and receivers **32**, **36** on both the first C-arm **24** and second C-arm **26** are in the same plane. The second C-arm **26** accordingly is movable from a navigating position to a secondary imaging position in as little as 10 seconds.

The second C-arm **26** provides a minimum articulation of the magnetic pods **22** to ensure compatibility with secondary imaging equipment. The second C-arm **26** is preferably translatable between an extended position and a retracted position, by virtue of a ceiling track **42** extending above the patient support table **44**. In one position, the second C-arm **26** is extended such that the magnetic pods **22** are moved into the plane comprising the imaging beam source on the first C-arm, to enable magnetic navigation in the operating region **28**. The magnetic pods **22** mounted on the second C-arm are positioned so that, in their navigating position, a line between the magnetic pods **22** is generally perpendicular to, and coplanar with a line between the imaging beam source **30** and the imaging beam receiver **32** mounted on the second C-arm **24**. the second C-arm is retracted such that the magnetic pods **22** are moved out of the plane to accommodate the imaging beam source **34** and imaging beam receiver **36** on the second C-arm in its imaging position. In the second secondary imaging position, the line between the imaging beam source **34** and imaging beam receiver **36** on the second C-arm **26** is generally perpendicular to, and coplanar with a line between the imaging beam source **30** and imaging beam receiver **32** on the first C-arm.

The first C-arm **24** is preferably mounted on a track **38** for enabling the C-arm to rotate about the radial center of the first C-arm **24**, such that the first C-arm **24** rotates in a generally circumferential arc about the operating region **28**. The track **38** is preferably mounted to a base unit having a drive mechanism for controlling the rotation of the first C-arm **24** about the operating region. The base unit for the first C-arm may be positioned on the floor in a location relative to a horizontal support table **44** for the patient, such that the longitudinal axis of the patient is within the operating region **28**. In the first embodiment, a standing C-arm imaging system is provided as shown in FIG. **3**. The C-arm shown is a standing Siemens C-arm imaging system, but may alternatively be any equivalent imaging system capable of rotation about an operating region of a patient. The horizontal support table **42** may also be moved in a direction along the longitudinal axis of the patient, to position a desired area of the subject's body within the operating region **28**.

The second embodiment further comprises a second C-arm **26** that is mounted on a track support **40** for enabling the second C-arm to rotate about the radial center of the second C-arm **24**. The second C-arm **24** rotates in a generally circumferential arc about the operating region **28**. The second C-arm **26** shown in FIG. **3** is preferably an overhead secondary Siemens C-arm, but may alternatively be any equivalent system capable of rotation about an operating region of a patient. The track support **40** is preferably mounted via a motorized trolley or travel mechanism to an overhead linear track that is parallel to the longitudinal axis of the patient and/or support table. The overhead linear track enables the second C-arm **26** to be moved to a first imaging position, where a line between the imaging beam source **34** and receiver **36** on the second C-arm **26** is generally perpendicular to, and coplanar with a line between the imaging beam source **30** and imaging beam receiver **32** on the first C-arm **24**. The second C-arm **26** can also be moved to a second navigating position, where a line between the pair of magnetic navigational pods **22** on the second C-arm **26** is generally perpendicular to, and coplanar with a line between the imaging beam source **30** and imaging beam receiver **32** on the first C-arm **24**. Thus, the second C-arm **26** can provide for secondary imaging of the operating region that may be required during a procedure in which a medical device is being magnetically navigated within the subject's body.

Referring to FIGS. **12**-**18**, a third embodiment of a system is provided that also enables both primary and secondary imaging as well as magnetic navigational control within a subject's body. The system comprises magnetic navigational equipment **22** that may be moved from a first navigational position to a second position for enabling secondary imaging equipment to have access to the operating region of the subject's body, for example, during a procedure where additional views of the patient are required for the procedure. The system generally comprises a first imaging equipment support structure **24** having a generally C-shaped configuration, and a second imaging equipment support **26** structure having a generally C-shaped configuration **26**. The first and second C-arm structures **24** and **26** are preferably mounted on tracks that enable the C-arms to rotate in a generally circumferential arc about an operating region **28** of the subject's body as shown in FIG. **12**. In the third embodiment, the system comprises a first C-arm **24** with an imaging beam source **30** and an imaging beam receiver **32** that are mounted on the first C-arm **24** and positioned to be disposed on opposite sides of the operating region **28** for imaging the operating region. The imaging beam receiver **32** may be configured to accommodate an imaging plate of approximately 20 centimeters, and may preferably accommodate an imaging plate of up to approximately 30 centimeters. The operating region **28** is represented by a sphere of approximately 12 inch diameter as shown in FIG. **1**, which represents a patient's head plus 1 inch of additional clearance. The system also comprises a second C-arm **26** with an imaging beam source **34** and an imaging beam receiver **36** that are mounted on the second C-arm **26**. The imaging beam source **34** and imaging receiver **36** are positionable to be disposed on opposite sides of the operating region **28** for imaging the operating region. The first C-arm **24** and second C-arm **26** are movably mounted via tracks **38** and **40**, to permit coordinated simultaneous rotation of the first C-arm **24** and the second C-arm **26** in a generally circumferential arc about the operating region **28** of the subject's body as shown in FIG. **1**. The first and second C-arms may be controllably rotated about the patient by a servo drive motor mechanisms preferably controlled by a computer system that is integrated with both the imaging and navigational equipment. In this manner, the computer control of the imaging and navigational equipment may provide for seamless coordination of movement of both systems to provide either imaging operation, navigation control or both.

The second C-arm **26** is movable between an imaging position and a stowed position. In the imaging position, the imaging beam source **34** and imaging beam receiver **36** on the second C-arm **26** are positioned so that the imaging beam sources **30**, **34** and receivers **32**, **36** on both the first C-arm **24** and second C-arm **26** are in the same plane. In the stowed position, the second C-arm **26** is retracted away from the plane via a ceiling track **42**, to provide accessibility for the magnetic navigation pods **22** on the first C-arm **24**. The pair of magnetic pod units **22** are rotated or aligned to project towards the operating region. The pair of magnetic pods **22** are movably mounted on the first C-arm **24**, such that the pods may be switched between a navigating position and a stowed position. In navigating position, the pods **22** are disposed on opposite sides of the operating region **28** in the same plane as the imaging beam source **30** and the imaging beam receiver **32** mounted on the first C-arm. The magnetic pods **22** are capable of applying a navigating magnetic field of at least 0.8 T in any direction to the operating region **28**. The pair of magnetic pods **22** are preferably positioned relative to each other to provide a 12 inch pod-to-pod separation. Such separation permits the magnetic navigation equipment to be utilized for INR or Neurosurgery therapies. The magnetic pods **22** each have a weight of approximately 120 pounds.

The first C-arm **24** provides a minimum articulation of the magnetic pods **22** to ensure compatibility with secondary imaging equipment on the second C-arm **26**. In the stowed position, the magnetic pods **22** are moved out of the plane comprising the imaging beam source on the first C-arm, to provide accessibility for the imaging beam source **34** and imaging beam receiver **36** on the second C-arm **26** to move into an imaging position. The magnetic pods **22** are preferably able to pivot or rotate away from the patient to provide a separation of at least 30 inches to accommodate positioning of the patient between the primary and secondary imaging sources. The imaging beam source **30** and the imaging beam receiver **32** mounted on the first C-arm **24** are positioned so that a line between the imaging beam source **30** and receiver **32** is generally perpendicular to, and coplanar with a line between the magnet pods **22** in their navigating position. In the secondary imaging position, the line between the imaging beam source **30** and receiver **32** on the first C-arm **24** is generally perpendicular to, and coplanar with a line between the imaging beam source **34** and imaging beam receiver **36** on the second C-arm **26**.

The first C-arm **24** is preferably mounted on a track **38** for enabling the C-arm to rotate about the radial center of the first C-arm **24**, such that the first C-arm **24** rotates in a generally circumferential arc about the operating region **28**. The track **38** is preferably mounted to a base unit having a drive mechanism for controlling the rotation of the first C-arm **24** about the operating region. The base unit for the first C-arm may be positioned on the floor in a location relative to a horizontal support table **44** for the patient, such that the longitudinal axis of the patient is within the operating region **28**. In the first embodiment, a standing C-arm imaging system is provided as shown in FIG. **12**. The C-arm shown is a standing Siemens C-arm imaging system, but may alternatively be any equivalent imaging system capable of rotation about an operating region of a patient. A neuro-navigation system is integrated with the C-arm in a pivotal arrangement, where the first C-arm **24** comprises two magnetic pods **22** mounted on extension arms **46** that are pivotally secured to the first standing C-arm. The magnetic pods **22** may swivel or rotate on the first C-arm away from the operating region of the patient. When pivoted away from the patient, access is provided for a second C-arm **26** that may be moved into alignment with the first standing C-arm to permit secondary imaging of the operating region of the patient. The horizontal support table **44** may also be moved in a direction along the longitudinal axis of the patient, to position a desired area of the subject's body within the operating region **28**.

The third embodiment further comprises a second C-arm **26** that is mounted on a track support **40** for enabling the second C-arm to rotate about the radial center of the second C-arm **24**. The second C-arm **24** rotates in a generally circumferential arc about the operating region **28**. The track support **40** is preferably mounted via a motorized trolley or travel mechanism to an overhead linear track **42** that is parallel to the longitudinal axis of the patient and/or support table **44**. The overhead linear track **42** enables the second C-arm **26** to be moved to a secondary imaging position, such that a line between the imaging beam source **30** and receive **32** on the first C-arm **24** is generally perpendicular to, and coplanar with a line between the imaging beam source **34** and imaging beam receiver **36** on the second C-arm **26**. The second C-arm **26** shown in FIG. **12** is preferably an overhead secondary Siemens C-arm, but may alternatively be any equivalent system capable of rotation about an operating region of a patient. Thus, the second C-arm can provide for secondary imaging of the operating region that may be required during a procedure in which a medical device is being magnetically navigated within the subject's body.

The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention.

What is claimed is:

1. A system for imaging and magnetically navigating a medical device within an operating region in a subject's body, the system comprising: a first C-arm; a first imaging beam source and a first imaging beam receiver mounted on the first C-arm and positioned to be disposed on opposite sides of the operating region to image the operating region; a second C-arm; a second imaging beam source and a second imaging beam receiver mounted on the second C-arm and positionable to be disposed on opposite sides of the operating region to image the operating region; the second C-arm being movable between an imaging position in which the second imaging beam source and second imaging beam receiver on the second C-arm are positioned so that the first and second imaging beam sources and first and second imaging beam receivers are in the same plane, and a stowed position in which the second C-arm is in a navigating position; and a pair of magnetic pods movably mounted on the first C-arm, the magnetic pods being movable between a navigating position in which the pods are disposed on opposite sides of the operating region in the same plane as the second imaging beam source and the second imaging beam receiver, for applying a navigating magnetic field of at least 0.08 T in any direction to the operating region, and a stowed position in which the magnets are moved out of the plane to accommodate the second imaging beam source and second imaging beam receiver on the second C-arm in its imaging position.

2. The system according to claim **1** wherein the first imaging beam source and the first imaging beam receiver are positioned so that a line between the first imaging beam source and first imaging beam receiver is generally perpendicular to, and coplanar with a line between the magnet pods in their navigating position.

3. The system according to claim **2** wherein the second imaging beam source and the second imaging beam receiver on the second C-arm are positioned so when the second C-arm is in its imaging position, a line between the second imaging beam source and second imaging beam receiver is generally perpendicular to, and substantially coplanar with a line between the first imaging beam source and first imaging beam receiver on the first C-arm.

4. The system according to claim **1** wherein the first C-arm is mounted on the floor.

5. The system according to claim **1** further comprising a patient support having a head and a foot, and wherein the first C-arm is positioned at the head.

6. The system according to claim **5** wherein the second C-arm moves toward and away from the patient in a direction parallel to the patients longitudinal axis.

7. The system according to claim **1** wherein the magnet pods pivot about an offset axis to move out of the plane with the first imaging beam source and first imaging beam receive on the first C-arm, to accommodate movement of the second C- arm.

8. The system according to claim **1** wherein the magnetic pods translate to accommodate movement of the second C-arm.

9. A system for imaging and magnetically navigating a magnetically responsive medical device within an operating region in a subject's body, the system comprising: a first C-arm; a first imaging beam source and a first imaging beam receiver mounted on the first C-arm so that the first imaging beam source and first imaging beam receiver can be disposed on opposite sides of the operating region in the subject; a second C-arm, movable relative to the first C-arm between a stowed position and an imaging position; a second imaging beam source and a second imaging beam receiver mounted on the second C-arm so that when the second C-arm is in its imaging position, the second imaging beam source and second imaging beam receiver can be disposed on opposite sides of the operating region, in substantially the same plane as the first imaging beam source and first imaging beam receiver on the first C-arm; a pair of magnetic pods movably mounted on the first C-arm, the magnetic pods being movable between a navigating position in which the pods are disposed on opposite sides of the operating region in the same plane as the second imaging beam source and the second imaging beam receiver, for applying a navigating magnetic field of at least

0.08 T in any direction to the operating region, and a stowed position in which the magnets are not on opposite sides of the operating region to accommodate the second imaging beam source and second imaging beam receiver on the second C-arm in its imaging position.

10. The system according to claim **9** wherein the first imaging beam source and the first imaging beam receiver are positioned so that a line between the first imaging beam source and first imaging beam receiver is generally perpendicular to, and coplanar with a line between the magnet pods in their navigating position.

11. The system according to claim **10** wherein the second imaging beam source and the second imaging beam receiver on the second C-arm are positioned so when the second C-arm is in its imaging position, a line between the second imaging beam source and second imaging beam receiver is generally perpendicular to, and substantially coplanar with a line between the first imaging beam source and first imaging beam receiver.

12. The system according to claim **9** wherein the first C-arm is mounted on the floor.

13. The system according to claim **9** further comprising a patient support having a head and a foot, and wherein the first C-arm is positioned at the head.

14. The system according to claim **13** wherein the second C-arm moves toward and away from the patient in a direction parallel to the patients longitudinal axis.

15. The system according to claim **9** wherein the magnet pods pivot about an offset axis to move out of the plane with the first imaging beam source and first imaging beam receive on the first C-arm, to accommodate movement of the second C-arm.

16. The system according to claim **9** wherein the magnetic pods translate to accommodate movement of the second C-arm.

17. A system for imaging, and magnetically navigating a magnetically responsive medical device within an operating region in a subject's body, the system comprising: a first C-arm; a first imaging beam source and a first imaging beam receiver mounted on the first C-arm so that the first imaging beam source and first imaging beam receiver can be disposed on opposite sides of the operating region in the subject; a second C-arm, movable relative to the first C-arm between an imaging position and a navigating position; a second imaging beam source and a second imaging beam receiver mounted on the second C-arm so that when the second C-arm is in its imaging position, the second imaging beam source and second imaging beam receiver can be disposed on opposite sides of the operating region, in substantially the same plane as the first imaging beam source and first imaging beam receiver on the first C-arm; a pair of magnetic pods mounted on the second C-arm, the magnetic pods being positioned on the C-arm so that when the second C-arm is in its navigation position, the magnetic pods are disposed on opposite sides of the operating region in the same plane as the second imaging beam source and the second imaging beam receiver on the first C-arm, for applying a navigating magnetic field of at least 0.08 T in any direction to the operating region.

18. The system of claim **17** wherein the second imaging beam source and the second imaging beam receiver on the second C-arm are positioned so when the second C-arm is in its imaging position, a line between the second imaging beam source and second imaging beam receiver is generally perpendicular to, and substantially coplanar with a line between the first imaging beam source and first imaging beam receiver on the first C-arm.

19. The system according to claim **17** wherein the second C-arm moves toward and away from the patient in a direction parallel to the patients longitudinal axis.

20. The system of claim **19** wherein the magnet pods are generally adjacent to the second imaging beam source and second imaging beam receiver mounted on the second C-arm, such that the second C-arm may move from a navigation position in which the magnet pods are disposed on opposite sides of the operating region in the same plane as the first imaging beam source and the first imaging beam receiver on the first C-arm, and an imaging position in which the second imaging beam source and second imaging beam receiver mounted on the second C-arm are disposed on opposite sides of the operating region in the same plane as the first imaging beam source and the first imaging beam receiver on the first C-arm.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 7,603,905 B2
APPLICATION NO. : 11/483397
DATED : October 20, 2009
INVENTOR(S) : Francis M. Creighton, IV

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page:

The first or sole Notice should read --

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 668 days.

Signed and Sealed this

Fifth Day of October, 2010

David J. Kappos

David J. Kappos
Director of the United States Patent and Trademark Office